ROLE OF TRANSVERSE POLARIZATION IN CONSTRAINING NEW PHYSICS

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Transverse polarization (TP) can be used to study interference of (S, P) or T type couplings from new physics with SM contribution. In $e^+e^- \to t\bar{t}$, a CP-odd azimuthal asymmetry can constrain the scale Λ of new (S, P) or T contact interactions to be higher than about 7 TeV for $\sqrt{s} = 500$ GeV, $\int \mathcal{L}dt = 500\text{fb}^{-1}$, and assuming 80% e^- and 60% e^+ polarizations in opposite directions. In $e^+e^- \to \gamma Z$ without chirality violation, but with CP-violating anomalous $\gamma\gamma Z$ couplings, an azimuthal asymmetry can probe the anomalous coupling down to about 10^{-2}.

Longitudinally polarized beams are expected to be available at a linear collider. Spin rotators can then be used to convert longitudinal polarization to transverse polarization (TP). Can TP be used to get different information as compared to longitudinal polarization? Recent work which provides some answers to this question in various contexts is found in ref. [1]. Here we discuss the question in the context of some other new physics, mainly from the point of view of CP violation.

CP violation in $e^+e^- \to f\bar{f}$ needs either polarized e^+ and/or e^- beams or measurement of polarization of f and/or $\bar{f}$. An exception is when f is a neutral particle (like neutralino, γ, Z, etc), when $\vec{p}_e \cdot \vec{p}_f$ is CP odd, but even under naïve time reversal. With TP, one can construct CP-odd triple products which do not need the measurement of the final-state polarization, resulting in better statistics.

Assuming couplings of e^+e^- to new currents of the type V, A, S, P and T, it is found that the interference of SM γ and Z exchange with V, A couplings gives no CP-violating terms in the distribution, neglecting the electron mass. S and T couplings do give CP-violating azimuthal terms. These terms *do not need both* e^- and e^+ to be polarized.

For e^- and e^+ TP's parallel or anti-parallel, the azimuthal distribution has $\sin 2\phi$ and $\cos 2\phi$ terms, but no $\sin\phi$ and $\cos\phi$ terms if there is chiral invariance[2]. Thus, these latter terms can be used to study interference between SM amplitude and amplitude with new chirality-violating interactions. Such terms are absent with longitudinal polarization (or no polarization). This is where TP helps.

We illustrate these ideas using the processes $e^+e^- \to t\bar{t}$ with contact inter-

actions [3] and $e^+e^- \to \gamma Z$ with triple-gauge couplings [4]. A related discussion on $e^+e^- \to t\bar{t}$ with scalar leptoquark intermediate states may be found in [5].

For the process $e^+e^- \to t\bar{t}$, a model-independent four-Fermi Lagrangian for new physics, up to terms of dimension 6, is

$$\mathcal{L}^{4F} = \sum_{i,j=L,R} \Big[S_{ij} (\bar{e} P_i e)(\bar{t} P_j t) + V_{ij} (\bar{e}\gamma_\mu P_i e)(\bar{t}\gamma^\mu P_j t) + \frac{1}{2} T_{ij} (\bar{e}\sigma_{\mu\nu} P_i e)(\bar{t}\sigma^{\mu\nu} P_j t) \Big]. \tag{1}$$

With TP, the V term does not give CP violation, but the S and T terms do.

The angular distribution with S and T terms and TP's of the e^+ and e^- of opposite signs has an interference term proportional to Im$S\,\sin\theta\,\sin\phi$, which is odd under CP. We can then define a CP-odd asymmetry:

$$A(\theta_0) = \frac{1}{\sigma(\theta_0)} \int_{-\cos\theta_0}^{\cos\theta_0} d\cos\theta \left[\int_0^\pi \frac{d\sigma}{d\Omega} d\phi - \int_\pi^{2\pi} \frac{d\sigma}{d\Omega} d\phi \right], \tag{2}$$

where θ_0 is a cut-off, and $\sigma(\theta_0)$ is the total cross cross section with the cut-off θ_0. The asymmetry is proportional to the imaginary part of the combination $S \equiv S_{RR} + (2c_A^t c_V^e / c_V^t c_A^e)\, T_{RR}$.

The result for the 90% C.L. limit on ImS as a function of the cut-off θ_0 for the choice $\sqrt{s} = 500$ GeV, $\int \mathcal{L} dt = 500$ fb^{-1}, and 100% e^+ and e^- polarizations is shown in Fig. 1. Assuming dimensionless couplings to be $\mathcal{O}(1)$, the limit is

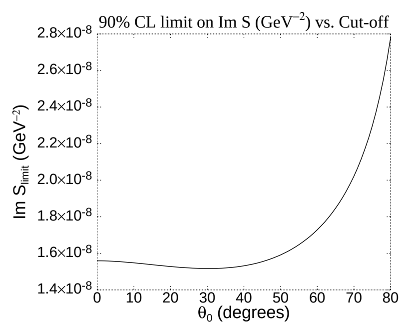

Figure 1: The 90% CL limit on Im S as a function of the cut-off θ_0.

seen to correspond to a new-physics mass scale of $\Lambda \approx 8$ TeV. With realistic values of polarization, viz., 80% for e^- and 60% for e^+, the asymmetry reduces by a factor 0.7, and the limit on Λ decreases to about 6.7 TeV. With only e^- polarization, the limit decreases to about 5 TeV.

We next consider the process $e^+e^- \to \gamma Z$. This process has a neutral final state, and it is possible to study CP violation with TP even without

chirality violating interactions. Asymmetry under $\theta \to \pi - \theta$ is a signature of CP violation, which is, however, even under T. With TP, there is another CP-odd, T-odd asymmetry, viz., asymmetry under change of sign of the variable $\sin^2\theta\cos\theta\sin 2\phi$. We illustrate this for the concrete case where CP violation arises from anomalous $\gamma\gamma Z$ and γZZ couplings.

The Lagrangian for anomalous CP-violating couplings of dimension 6 is

$$\mathcal{L}_{\rm anom} = \frac{e}{m_Z^2} F_{\mu\nu}\left[\lambda_1 \partial^\mu Z^\lambda \partial_\lambda Z^\nu + \frac{1}{16 c_W s_W}\lambda_2 F^{\nu\lambda}\left(\partial^\mu Z_\lambda + \partial_\lambda Z^\mu\right)\right]. \qquad (3)$$

The resulting angular distribution of γ has terms dependent on Im λ_1, Re λ_2 and Im λ_2. We define an asymmetry A_1 proportinal to Re λ_2, corresponding to the difference in the forward-backward asymmetries of events with $\sin 2\phi > 0$ and with $\sin 2\phi < 0$. The 90% CL limits that can be obtained on Reλ_2 using A_1 is Re $\lambda_2 < 6.2 \times 10^{-3}$ assuming a cut-off of 26°.

To conclude, TP can be used to study interference of (S, P) or T type couplings from new physics with SM contribution, which is not possible with longitudinal polarization. For the case of TP with $\vec{s}_{e^-} = -\vec{s}_{e^+}$, CP-odd asymmetry corresponding to $\sin\phi \to -\sin\phi$ can be used to limit new (S, P) or T interactions. In case of contact (S, P, T) interactions in the process $e^+e^- \to t\bar{t}$, limits that can be put on the new-physics scale Λ is $\Lambda <$ 7 TeV for $\sqrt{s} = 500$ GeV and $\int \mathcal{L} dt = 500$ fb^{-1}, assuming 80% e^- polarization and 60% e^+ polarization.

For neutral final states it is possible to have additional CP-violating asymmetries with TP even without chirality violation. In $e^+e^- \to \gamma Z$ with CP violation arising from anomalous $\gamma\gamma Z$ and γZZ couplings, the $\gamma\gamma Z$ coupling gives rise to a CP-violating term proportional to $\sin^2\theta\,\cos\theta\,\sin 2\phi$ which is CP odd and T odd and hence proportional to Reλ_2. This term can be isolated by a specific asymmetry, and used to probe Reλ_2 down to about 10^{-2}.

References

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